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SENSITIVITY OF ESTIMATED FINANCIAL RETURNS ON TIMBER INVESTMENTS TO DATA ERRORS

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and Thomas P. Hart

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Sensitivity of Estimated Financial Returns on Timber Investments to Data Errors

by

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Abstract

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Concern is frequently expressed that financial return estimates in national scope timber investment analyses are unreliable because of excessive data errors.

This study addresses the concern through a sensitivity analysis by: determining the general level of sensitivity to data errors, determining sensitivity in order to set data collection accuracy standards, comparing stumpage price and treatment cost variations with allowable data changes to determine the proper level of investment case disaggregation, and comparing the relative sensitivity of the internal rate of return and present net worth investment criteria.

Results indicate that general sensitivity to data errors is relatively low, and that financial return estimates are more sensitive to data errors for cases with high rates of return. Average stand diameter, tract size, and treatment difficulty all influence stumpage prices and/or treatment costs enough to make them separate dimensions in the area matrix used to define potential treatment opportunities. Also, the internal rate of return criteria proved less sensitive to data errors at crucial decision points than the present net worth criteria.

KEYWORDS: Sensitivity analysis, investment criteria, data accuracy standards

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I. INTRODUCTION

Several major national scope studies of financial returns from timber management investments have been prepared. The first of recent reports was the *Timber Issue Paper* prepared for the Office of Management and Budget (OMB), (U.S. Department of Agriculture 1972). A second study was the Forest Service's transmittal to the President's Advisory Panel on Timber and the Environment (PAPTE), (USDA Forest Service 1972). The third study, *The Outlook for Timber in the United States* (USDA Forest Service 1973), incorporated many of the same softwood investment cases found in the transmittal to the PAPTE and added several regional investment studies.

These are not the first national scale studies which have analyzed timber management investment opportunities. The detailed analysis of National Forest opportunities by Marty and Newman (1969) is an earlier example. Likewise, these will certainly not be the last studies of their kind. The recent development of a financially oriented system for apportioning Forestry Incentives cost-share funds among the States demonstrates Forest Service interest in this type of analysis (Mills, et.al, 1974). Also, the Office of Management and Budget and the Comptroller General (GAO) (1974) have expressed continued and increasing interest in such timber investment analysis.

II. PROBLEM

A question is invariably raised when financial analyses of a national scope such as these are completed:

> "*How much do data errors influence the accuracy of financial return estimates; and how should decisions concerning data collection and level of analysis detail be adjusted to increase accuracy?*"

This question of data errors takes on two dimensions in national scope analyses. The first dimension is that of incorrectly estimating actual situations because of measurement or sampling error. The actual cost of ponderosa pine planting in the Rocky Mountains may be $50/acre. However, improper sampling of past planting costs or incorrect data tabulation may yield a $45/acre cost estimate.

An immediate reaction of some people to this first dimension is to call for more effort in data collection. The three major data elements can each be collected on at least two levels of detail, however, and the collection methods vary considerably in cost. For example, harvest volume estimates can be derived from empirical yield tables, or they can be estimated from stand projection models which differentiate harvest by quality and diameter (Gansner, et.al. 1973). Similarly, average treatment costs can be estimated from contract records (Row 1971) or more detailed estimates can be made by regressing total cost against specific treatment activities, such as number of trees marked for cutting (Anderson 1966). Average stumpage prices can be calculated from past timber sale records. Alternatively, prices can be estimated by regressing price upon specific stand conditions (Anderson 1966) or by elaborate "conversion surplus" approaches where different prices are specified for different diameter classes, stand densities, and site qualities (Herrick and Morse 1968). Which method should be used?

The second dimension of the data error question can more accurately be called "aggregation error". Of necessity, national scope studies analyze rather aggregated investment cases. For example, all of the acreage of ponderosa pine planting opportunities in the Rocky Mountains may be grouped into a single investment case and a single financial return estimated. If planting costs are too variable within this aggregate, the financial return estimated from aggregate averages may be quite different from the financial return on investments in subsets of the aggregate. If there is too much heterogeneity among treatment components and therefore financial returns in an aggregate, investments should be separately identified and analyzed for each of the components.

Some people react to this problem by calling for a disaggregation of investment cases below the level of aggregation previously employed. The analysis of National Forest investments prepared for the *Outlook* study had an area matrix with forest type group, site class, and stand size dimensions for eight administrative regions. This classification identified 984 separate area cells. Is this sufficient division to produce homogeneous treatment opportunities or should a terrain slope dimension also be added because of the impact of slope upon treatment and harvest cost? Should there be two slope classes, raising the number of

separate area cells to 1968, or are three slope classes necessary, raising the total to 2952?

These questions of data collection effort and level of dissaggregation should not be considered apart from an analysis of the sensitivity of financial return estimates and investment decisions to data changes or errors.

A sensitivity analysis may reveal that data variations within reasonable bounds of uncertainty have no material influence upon profitability in certain conditions. At the least, a sensitivity analysis will identify those conditions where data changes influence investment profitability the most. The sensitivity results, in conjunction with the relative cost of collecting data, will help set a priority schedule for more refined data collection and determine the amount of aggregation permitted.

III. STUDY OBJECTIVES

The question of how much data errors influence estimated financial return on timber investments and how the analysis should be modified to account for this impact is addressed with a sensitivity analysis through four interrelated objectives.

(1) Determine the overall sensitivity of estimated financial return to data errors across a broad range of investment cases representative of recent national scope studies. (Sections VIII and IX).

(2) Identify those investment situations where data errors have the greatest impact, so that data collection accuracy standards can be established. (Section IX).

(3) Compare the causes and magnitudes of treatment cost and stumpage price data relative to the allowable data changes for the sample cases in order to better determine the level of investment case aggregation permitted. (Section X).

(4) Determine the relative sensitivity of internal rate of return (IROR) and present net worth (PNW) to data errors. (Section IX).

Key to the study is intentional selection of investment cases using an analytical approach "representative of recent national investment scope studies". The concern is impact of errors within these analyses as they have been framed, not the development of a more sophisticated framework.

IV. RELATED STUDIES

Numerous research studies of individual treatments and species include tests of the sensitivity of financial returns to data changes. Lundgren (1965, 1966) estimated returns to red pine management at several stumpage price and cost levels. Herrick and Morse (1968) evaluated the profitability of oak-hickory reforestation and timber stand improvement at high, low, and average levels of both costs and stumpage prices. Manthy (1970) estimated the rate of return on investments in white pine, red pine, and larch plantations under two stumpage price assumptions. Anderson and Guttenberg (1971) estimated the returns to conversion of oak-hickory and oak-pine to loblolly and slash pine plantations at three stumpage price levels and a continuum of investment costs. Row (1973), in estimating the return on loblolly pine investments, included a stochastic analysis of insect, disease, and fire damage.

Some sensitivity results are available from these research reports. For example, Manthy estimated that the IROR for planting white pine increases 20 percent (6.6 to 7.9 percent) if stumpage prices are increased 100 percent ($38 to $76 per Mfbm). Dutrow et.al. (1970) found that the IROR for cottonwood planting in one of their cases is lowered 25 percent (10.0 to 7.5 percent) when plantation establishment cost is increased 100 percent ($50 to $100 per acre).

Unfortunately, there are not enough cases in research reports to encompass the scope of the nationwide studies. A broad scale sensitivity analysis of cases typical of those in past nationwide studies must be completed before anything definitive can be said about required accuracy or priorities for data collection.

V. STUDY SCOPE

The sensitivity analysis is based upon 46 separate National Forest timber investment cases selected from the 184 cases included in the *Outlook* study (USDA Forest Service 1973). All are softwood investments with a sawtimber objective. The sample cases were selected to cover a range of initial treatments, forest types, site classes, and National Forest Administrative Regions. Opportunities with the largest acreages were selected such that 51 percent of the reforestation acreage (20

cases) and 48 percent of the precommercial thinning (13 cases) and release treatment (13 cases) acreage studied in the *Outlook* report are included in this analysis. The cases analyzed are listed in Appendix A.

The cases are all analyzed as marginal investments. The return on additional investments is measured by subtracting the costs and benefits associated with "current management" from the costs and benefits resulting from an "intensified management" regime. Only timber-related costs and benefits are included. Both management levels entail entire treatment regimes, so they differ in more ways than just initial treatment cost. A single intense management level was evaluated for each case and a perpetual rotation is assumed in order to standardize the time horizon among cases. Two investment criteria were calculated: internal rate of return (IROR) and present net worth (PNW) discounted at 5 percent.

VI. SENSITIVITY TECHNIQUE

The technique for measuring the sensitivity to data errors was developed to answer the question:

> "How much of a percentage change in the base input of a particular data group is necessary to change the estimated financial return by a specified amount?"

A. *Error Threshold Concepts Employed.* The specified change in financial return or—stated another way—the error threshold in estimating financial return, can be constructed a number of ways for both investment criteria. It is essential that these financial return estimation error thresholds are understood because different patterns of sensitivity result from different threshold approaches.

The central threshold approach used in this study is a band about IROR of 1 percent interest rate. A case of longleaf-slash pine release will provide an example of the threshold levels and will be carried throughout as an example case. The case has an 8.82 percent IROR. The upper and lower IROR thresholds of the longleaf-slash example case are 9.92 percent and 7.82 percent, respectively. The sensitivity technique calculates how much of a percentage change in each data group is necessary to change the IROR from its base level (8.82 percent) to each of the error thresholds (9.92 and 7.82 percent).

A second threshold concept was developed to compare the sensitivity of IROR and PNW to data changes. Comparability is achieved by placing the financial return threshold levels the same percentage distance from the base profit level for both IROR and a "computed" PNW threshold. The percentage change between the base IROR and the IROR threshold levels is first calculated. This same percentage change is then applied to the base PNW to establish the "computed" PNW threshold. Generalized, the "computed" PNW thresholds are:

upper threshold:

$$PNW_B + \left(PNW_B * \frac{1 \text{ percent}}{IROR_B}\right) \quad (1)$$

lower threshold:

$$PNW_B - \left(PNW_B * \frac{1 \text{ percent}}{IROR_B}\right) \quad (2)$$

Where:

PNW_B = the base PNW of the case using original input data

$IROR_B$ = the base IROR of the case using original input data

For example, the 1 percent IROR threshold is $\frac{1}{8.82}$ or 11.3 percent of the 8.82 percent IROR on the longleaf-slash pine release example. When the 11.3 percent is applied to the PNW base of $123.45, the upper and lower threshold levels are $137.40 and $109.50, respectively.

B. *Data Groups Tested.* Six data groups are identified and the sensitivity to each is separately calculated; reforestation cost, precommercial thinning cost, release cost, commercial thinning volume, final harvest volume, and stumpage price. Sensitivity to errors or changes in these data elements is not calculated every time one is encountered. The sensitivity of financial returns to reforestation cost changes is only tested where reforestation is the initial action in the intensive manage ment regime. This same rule is followed for the other cost items. Sensitivity to commercial thinning and final harvest volume data errors is restricted to the volume estimates in the intensified management regime only. The harvest volume estimate in the current management regimes is held constant because harvest estimates are typically derived independently for the two management levels. The stumpage price sensitivity includes similar percentage price changes for commercial thinning and final harvest volumes in both levels of management because the same price assumption is typically used.

Sensitivity to errors is separately estimated for each data group. For example, the sensitivity to reforestation cost changes is tested first and then returned to its original value before the sensitivity of another data element is analyzed. The number of combinations of joint data changes is almost unlimited so none were included.

C. *Calculation of the Percentage Data Change.* Calculation of sensitivity for the IROR thresholds is based upon the difference between the investment's base PNW and the PNW at the threshold. The base PNW at the IROR is by definition zero. The PNW at the upper IROR threshold, which is the PNW at a discount rate of IROR + 1 percent, is negative for all the sample cases. Data changes which increase the PNW by the threshold amount will return the case's PNW to zero and therefore move the case's IROR to the upper threshold.

The contribution to total PNW of each of the six data groups is sparately calculated. For example, the PNW contribution of the cost group is the sum of all reforestation costs discounted at the threshold interest rate. Similarly, the PNW contribution of the stumpage price data group is the sum of all stumpage prices multiplied by their respective harvest volumes, discounted at the threshold interest rate. Therefore, the percentage increase in stumpage prices necessary to raise the PNW back to zero equals the total PNW change required divided by the PNW contribution of the stumpage price data group. The general formula for percentage data changes between the base and IROR thresholds is:

$$PC_i = \frac{PNW_T}{PNWC_i} * 100 \text{ percent} \qquad (3)$$

Where:

PC_i = percentage change of data elements in group i required to move the PNW from the base to the threshold level

PNW_T = PNW of the investment case at the threshold interest rate

$PNWC_i$ = the PNW contribution of data elements in group i, e.g. the sum of stumpage prices times harvest volumes, discounted at the threshold interest rate, is the $PNWC_i$ of the stumpage price data group

Essentially the same procedure is employed for the PNW threshold approaches. The total PNW change between the base and threshold level is compared with the PNW contribution of one of the data groups to determine the allowable change of that data group before the threshold is violated. For the "computed" PNW threshold, the allowable data change formula is:

$$PC_i = \frac{PNW_D}{PNWC_i} * 100 \text{ percent} \qquad (4)$$

Where:

PNW_D = the difference in PNW from its base level equal to the percentage change in IROR between its base and threshold level

This sensitivity technique differs from Schweitzer's (1970) partial derivates of the present net worth equation. The above formulas are not as flexible as the partial derivatives, but they meet the objectives of this study with a simple and straightforward empirical approach. Both approaches are deterministic rather than iterative. A computer program was written in Fortran IV for the Univac 1108 for this study (Goforth and Mills 1975). The program has a generalized financial return calculation capability and conducts the sensitivity analysis described herein.

VII. *DATA EMPLOYED*

Data employed in this analysis are similar to those used in recent national studies of investment opportunities. The management regimes and timber yields are the same ones used in the analysis for the *Outlook* study. Yields were estimated in cubic feet and converted to board feet at the rate of 4.5 board feet per cubic foot for thinnings and 6.0 for final harvest. The harvest estimates correspond to the yield from the acre treated, not the induced increase in allowable cut which may result within the current institutional setting.

Treatment costs are those expected in National Forests for fiscal years 1974–75. The total treatment cost is included rather than "direct costs". "Direct costs" are defined in the accounting system by what administrative level incurs them, not by whether they are marginal costs to total program scale in the economic sense. The total cost per acre is the effective marginal program cost in appropriation requests.

Average stumpage prices were derived from Forest Service records by species and Administrative Regions. The average high bids for 1969–1972 were weighted by the volume sold each year. This smooths out the highly variable relative price changes among regions and species which occur on a year to year basis. The price excludes

purchaser brush and slash disposal deposits which are actually treatment costs in a management sense.

Purchaser road credits are added to the average high bid stumpage price. This implicitly assumes that the roads are already in place in treatment areas or that the residual value of the road equals its construction cost. The cost of Forest Service sales preparation and administration is then subtracted from the sum of high bid price plus purchaser road credits.

VIII. AVERAGE LEVELS OF SENSITIVITY

The discussion so far has covered the analytical approach developed for calculating the sensitivity to data errors and the types of data employed in the 46 cases analyzed. This section discusses the average levels of sensitivity to data errors across all 46 sample investment cases. These averages provide a good "order of magnitude" index of sensitivity and a focal point for discussing the reasons that different sensitivity relationships exist.

The meaning of the average allowable data changes, the PC_i in equations (3) and (4), can be demonstrated by using the longleaf-slash pine release example. The base IROR is 8.82 percent. The percentage data changes necessary to violate the upper IROR threshold (9.92 percent) are −22.78 percent for release cost, 22.83 percent for commercial thinning volume, 254.56 percent for final harvest volume, and 30.57 percent for stumpage price. Given a release cost of $51 per acre and holding all other data elements at their base value, the release cost estimate must be 22.78 percent lower ($39.33/acre) before the estimated IROR of the case is raised from 8.82 percent to 9.82 percent. Similarly, if the release cost estimate is returned to its original value, the estimated stumpage price must be 30.57 percent higher before the IROR estimate is raised to 9.92 percent. Thus, the base level stumpage price of $38 .21 per thousand board feet for commercial thinnings and $50.94 per thousand for final harvest volume must be raised to $49.89 and $66.51 per thousand board feet, respectively.

Similar allowable percentage changes (PC_i) were calculated for each of the 46 investment cases and averaged together (table 1). The standard deviation (SD) of individual cases about the mean is high for many data groups. The next section addresses this high deviation by pinpointing the individual case conditions where sensitivity to data errors is greatest.

A. *Fixed IROR Threshold Spans*. The allowable percentage data errors necessary to violate the ± 1 percent IROR accuracy thresholds are quite large. On the average, the true treatment cost may be only half as large as the estimated cost or almost twice as large as the estimated cost before the estimated IROR differs from the true IROR by over 1 percent (table 1). The accuracy of return item data can be even more slack. True return item values (stumpage prices, commercial thinning volumes, and final harvest volumes) must be over two and a half times larger than the estimated values before the true IROR is 1 percent higher than the estimated IROR. Any reasonable procedure for data collection will provide estimates within these accuracy bounds. The question of the most appropriate level of aggregation must still be answered, and it is addressed in Section X. For any given level of aggregation, however, these results indicate that any reasonable data collection procedure will supply accurate enough data on the average.

Before identifying those cases where sensitivity is greatest, what are the reasons for the relative sensitivities between data errors on cost and return items and between the upper and lower IROR thresholds? At the upper threshold, estimated IROR is more sensitive to cost data errors than return data errors. Conversely, IROR is more sensitive to return data errors than cost data errors at the lower IROR threshold.

The sensitivity relationships of cost versus lower IROR thresholds are dominated by two factors: the 2 percent difference in discount rates between the two IROR thresholds, (IROR + 1 percent) and (IROR − 1 percent), and the slope characteristics of the PNW function. The PNW function is the PNW versus discount rate relationship. First, since costs and returns are discounted at the IROR, there is a 2 percent difference in discount rate between the two IROR thresholds. For example, the $[1/(1+i)^n]$ discount factor at the lower threshold from the mean IROR is 0.279 for the average year of final harvest (86 years), but it is only 0.015 for the upper threshold. Therefore, if the discount factor was the only force, changes in

TABLE 1.—*The independent percentage change of separate data elements necessary to violate specified financial return estimation error thresholds, by threshold concept*

		upper limit IROR[1]		lower limit IROR[1]		"computed" PNW[2]	
	number of cases	mean percent	SD	mean percent	SD	mean percent	SD
Cost Data Elements							
reforestation cost[3]	20	−62.17	18.20	180.61	224.17	64.85	82.10
precommercial thinning cost[4]	13	−47.41	19.31	136.93	102.74	40.38	29.93
release cost[5]	13	−39.89	20.50	256.99	511.83	33.07	21.42
mean[6]		−51.70		189.85		48.95	
Return Data Elements							
commercial thinning volume	46	106.12	117.40	−63.01	44.72	1,372.49	4,443.29
final harvest volume	46	[7]601.89	2,496.72	−207.45	795.59	3,050.47	11,362.15
stumpage price	46	100.17	62.61	−45.69	15.58	1,258.30	3,368.32
mean		269.39		−105.38		1,893.75	

[1] The upper and lower IROR thresholds are set at 1 percent interest rate above and below the base level IROR for each case.

[2] The "computed" PNW thresholds are set a percentage distance from the base PNW equal to (1 percent/IROR) for each case. The sensitivity level is the same for both upper and lower thresholds. The sign of the percentage change is the same as those for IROR. PNW is calculated with a 5 percent discount rate.

[3] The mean IROR on cases where reforestation is the initial treatment is 2.72 percent. SD stands for the standard deviation of observations about the mean.

[4] The mean IROR on cases where precommercial thinning is the initial treatment is 3.82 percent.

[5] The mean IROR on cases where release is the initial treatment is 6.24 percent.

[6] The mean IROR on all cases analyzed is 4.02 percent.

[7] The mean percentage data change necessary to violate the upper IROR threshold for final harvest is only 169.84 percent if the two top IROR cases are excluded (14.75 percent and 10.97 percent IROR).

future values would have to be larger to violate the upper threshold than the lower threshold.

Second, the slope of the PNW function has an impact upon sensitivity relations because slope determines the PNW difference between the base level and threshold PNW which data changes must overcome in equations (3) and (4). The PNW function has a typical hyperbolic shape for all the sample cases. The PNW function starts at infinity and declines as the discount rate increases, crosses zero at the IROR, and asymptotically approaches initial cost. None of the PNW functions for the sample cases crossed zero more than once even though the foregone final harvest in the current management regime raises the possibility.

The PNW slopes displayed two characteristics relevant to the sensitivity relationships. They are:

(1) the slope for any particular case decreases as the interest rate increases, and

(2) the slope at the IROR is larger for cases with low IROR's than cases with high IROR's.

These slope relations are apparent in figure 1. They were verified by regressing the slope between the base IROR and the upper threshold, and the slope between the base and lower threshold against the inverse of IROR.[1] Using these equations, the PNW slope between the mean IROR (4.0 percent) and the upper threshold (5.0 percent) is $33.71. The slope between the mean IROR and the lower threshold (3.0 percent) is $91.04. This slope difference tends to yield a lower sensitivity to data errors at the lower threshold than at the upper threshold.

[1] $\text{Slope}_u = 13.776 + 80.2559\,(1/\text{IROR})$ $R^2 = .66$
$(9.2)^*$

$\text{Slope}_L = 109.2083 + 805.1946\,(1/\text{IROR})$ $R^2 = .77$
$(11.2)^*$

where:

Slope_u = PNW slope between base IROR and upper IROR threshold

Slope_L = PNOW slope between base IROR and lower IROR threshold

$*$ = calculated t-value

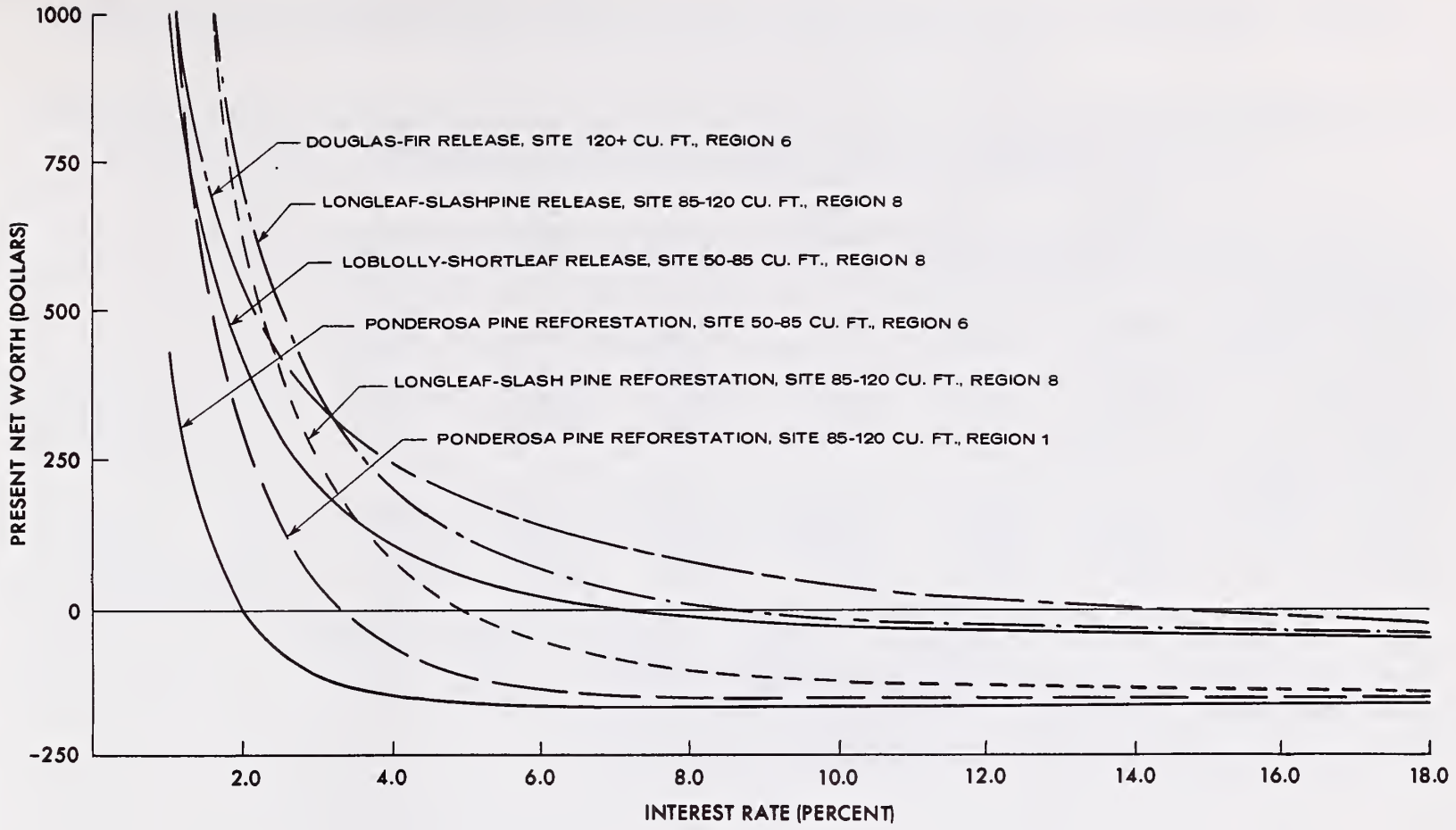

Figure 1.—The slope of the PNW function increases at the IROR as the IROR increases.

Since cost items generally occur in year zero, this PNW slope difference dominates the relative sensitivity for cost items between thresholds. The greater slope produces a larger allowable cost data change at the lower threshold than the higher. Thus, if the probability of cost estimation errors is symmetrical, there is a greater probability of overestimating IROR than of underestimating IROR due to cost errors. Stated differently, random cost estimation errors bias the estimated IROR upward.

The allowable percentage change of return data elements is also influenced by the PNW slope. The relative sensitivities at the two thresholds depend upon the net impact of slope and discount rate forces. The smaller allowable percentage data change at the upper threshold for return items indicates that the discount rate differential dominates over the PNW slope impact. This conclusion is supported by the smaller allowable data change at the threshold for commercial thinning than for the final harvest volume change. The earlier occurrence of commercial thinning reduces the discount rate impact. At least this is true on the average. The relative balance of these two forces has to be struck in each case.

Contrary to cost errors then, if the probability of return data estimation errors is symmetrical, random return data errors tend to bias the average estimated IROR downward. How much the conflicting return and cost biases of IROR counterbalance each other is a function of the relative distributions of estimation error and allowable percentage data changes.

The sensitivity of IROR to cost data errors is relatively unchanged by rather sizeable changes in the acceptable financial return estimation error. For example, the average allowable percentage cost data change for an upper IROR error threshold of 0.5 percent is −31 percent. It is only −71 percent when the threshold is 2.0 percent above the base (table 2). Return data items, however, are significantly affected by the error threshold band width, mostly because of the impact of discount rate differences between the thresholds.

B. "*Computed*" *PNW Thresholds*. The "computed" PNW thresholds, which were set a percentage distance from the PNW base equal to the distance between the IROR threshold and IROR base, were included simply for the sake of com-

TABLE 2.—*The independent percentage change of separate data elements necessary to increase the estimated IROR by various specified amounts*[1]

	0.5 percent		1.0 percent		1.5 percent		2.0 percent	
	mean percent	SD	mean percent	SD	mean percent	SD	mean percent	SD
Cost data elements								
reforestation cost	−39.50	15.90	−62.17	18.20	−76.76	17.54	−86.52	16.04
precommercial thinning cost	−29.59	14.02	−47.41	19.31	−58.99	20.76	−67.05	20.48
release cost	−24.68	15.37	−39.89	20.50	−50.45	21.92	−58.33	21.78
Return data elements								
commercial thinning volume	48.33	50.40	106.12	117.40	177.82	208.71	269.03	334.28
final harvest volume	[2]224.83	925.51	[3]601.89	2,496.72	[4]1,213.15	5,048.39	[5]2,180.98	9,068.33
stumpage price	41.53	23.21	100.17	62.61	182.18	126.02	296.01	224.01

[1] The increases are percentage points of interest rate rather than a percentage increase of the base IROR.
[2] Percentage increase is 65.16 when the two highest IROR cases are excluded.
[3] Percentage increase is 169.84 when the two highest IROR cases are excluded.
[4] Percentage increase is 336.91 when the two highest IROR cases are excluded.
[5] Percentage increase is 602.31 when the two highest IROR cases are excluded.

parison. An elasticity calculation[2] produces the same relative levels of sensitivity as this "computed" PNW threshold approach.

The average allowable cost data change is roughly the same for the "computed" PNW threshold—49 percent— as for the upper IROR threshold—52 percent (table 1). For the return items, however, the average allowable data change is considerably higher for the "computed" PNW threshold (1894 percent) than the upper IROR threshold (269 percent). Therefore, while there would be little problem with reasonable data accuracy using an IROR criterion, on the average, there would be even less of a problem with the PNW appoach, at least on the average.

Similar to the IROR threshold patterns, there are two reasons for the sensitivity pattern: relative discount rates, and the PNW change between the base and threshold levels. First, the "computed" PNW is discounted at 5 percent while the average IROR is only 4.0 percent. This higher PNW discount rate results in a lower average sensitivity to return data errors than is experienced using the IROR threshold. Table 3 demonstrates the large reduction in sensitivity to return data errors associated with higher discount rates.

[2] Elasticity here is calculated as allowable percentage data change over percentage change in the base profit level.

Second, the allowable percentage data change under the "computed" PNW criterion is influenced by the PNW difference between the base and threshold level through equation (4). The threshold PNW change is a function of:

(1) the percentage change in the base IROR between the base and threshold, (1/IROR) * 100 percent, and

(2) the base PNW to which the percentage change is applied.

The percentage change in the base PNW is constant for any particular case and IROR threshold, but the base PNW is a function of the discount rate. If the discount rate is significantly above or below the IROR, a large base PNW results while a discount rate close to the IROR produces a small PNW base. This is demonstrated in figure 1. The sensitivity to cost data changes is controlled almost exclusively by this discount rate vs. IROR relationship, as table 3 shows. That is, as the IROR of a particular case approaches the PNW discount rate, sensitivity to data errors increases. The sensitivity to cost items is remarkably stable across discount rates relative to the return data item, however.

TABLE 3.—*The independent percentage change of separate data elements necessary to violate the "computed" PNW threshold when PNW is discounted at different interest rates.*[1]

	2.5 percent discount		5.0 percent discount		10.0 percent discount		15.0 percent discount	
	mean percent	SD	mean percent	SD	mean percent	SD	mean percent	SD
Cost Data Elements								
reforestation cost	74.77	77.09	64.83	82.10	69.10	70.11	67.27	66.67
precommercial thinning cost	52.45	47.87	40.38	29.93	40.67	31.30	42.36	29.74
release cost	73.56	44.68	33.07	21.42	24.59	26.07	26.10	25.17
Return Data Elements								
commercial thinning volume	215.62	659.69	1,373.22	4,443.07	38,213.79	[2]	1,022,844.59	[2]
final harvest volume	191.35	642.35	3,053.33	11,361.44	584,486.07	[2]	[2]	[2]
stumpage price	140.59	379.69	1,561.06	3,863.28	47,175.01	[2]	1,399,779.22	[2]

[1] See footnote 2 in table 1.

[2] The value is above 9,999,999.99.

C. *Fixed Percentage PNW Thresholds*. Again for the sake of comparison, fixed percentage PNW thresholds were analyzed. Essentially the same sensitivity relationships discovered for the "computed" PNW criterion influence a more statistically conventional PNW threshold concept. The alternative approach places PNW thresholds a fixed percentage distance from the base. Thus:

$$PNW_T = PNW_B \times (PNW_B \times X \text{ percent})$$

where:

PNW_T = the threshold PNW at the assigned discount rate,

PNW_B = the base PNW at the assigned discount rate, and

X percent = the fixed percentage distance between the base and thresholds.

The average allowable percentage change using a fixed ± 10 percent threshold band is shown in table 4 for four different discount rates.

TABLE 4.—*The independent percentage change of separate data elements necessary to violate a ± 10% PNW threshold when PNW is discounted at different interest rates*[1]

	2.5 percent discount		5.0 percent discount		10.0 percent discount		15.0 percent discount	
	mean percent	SD	mean percent	SD	mean percent	SD	mean percent	SD
Cost Data Elements								
reforestation cost	14.85	14.46	7.64	3.68	10.43	0.57	10.37	0.27
precommercial thinning cost	29.60	54.74	11.60	12.85	8.28	2.66	9.39	1.14
release cost	59.40	58.46	19.34	18.37	7.43	4.12	8.18	2.73
Return Data Elements								
commercial thinning volume	17.83	30.48	91.07	211.04	2,262.63	6,680.29	55,742.41	[2]
final harvest volume	15.84	27.45	203.31	495.52	35,408.31	[2]	5,793,311.51	[2]
stumpage price	13.42	17.28	102.88	170.78	3,609.95	7,266.15	104,352.94	[2]

[1] The threshold levels are set at $PNW_B \pm (PNW_B * 10 \text{ percent})$ where PNW_B is the PNW of base input data.

[2] The value is above 9,999,999.99.

IX. CASE-TO-CASE VARIATION, DATA ACCURACY STANDARDS, AND THE RELATIVE SENSITIVITY OF INVESTMENT CRITERIA

The 46 investment cases varied significantly in their sensitivity to data errors as is apparent in the standard deviation measurements of table 1. For example, the true final harvest volume for the ponderosa pine reforestation case in Region 3 (site 20–50 cu.ft.) must be 300 percent above the estimated value before IROR is underestimated by 1 percent. For the ponderosa pine precommercial thinning case in Region 5 (site 120+ cu.ft.), however, true harvest volume can only be 35 percent above the estimated volume before the same IROR estimation error results.

Uniform data collection accuracy standards are not required, but the incidence of high sensitivity must be identified before data accuracy standards are established. Any reasonable data collection procedure may suffice for average condtions, but there is substantial variation about the average.

The conditions which produce the greatest sensitivity to data errors were identified by regressing the allowable percentage data change against five investment case conditions or parameters, including:

(1) IROR of the case or its inverse,
(2) year of final harvest,
(3) total timber harvest per acre derived from commercial thinnings and final harvest,
(4) stumpage price per thousand board feet for final harvests, and
(5) initial treatment cost per acre.

Except for IROR, the value of these parameters refer to the intensified management regime alone. Cases from all three initial treatments were pooled together for the regressions to obtain sufficient observations.

Four regression equations were fitted to these sample observations. There is one equation each which estimates the percentage allowable change in initial cost, commercial thinning volume, final harvest volume, and stumpage price data necessary to violate the upper IROR threshold. Regressions for the "computed" PNW criterion are also included, again for the sake of comparison.

A. *Relationship Between the IROR and Sensitivity to Data Errors with the IROR Criteria.* The regression equations explain an average of 86 percent of the variation in allowable data change (table 5). Coefficients for the IROR variable are consistent with the hypotheses about the PNW function slope and the discount rate forces discussed in Section VIII. The allowable error for initial cost, stumpage price, and commercial thinning volume data *decreases* as the case's IROR *increases*. The data accuracy standards must therefore be more stringent for these three data groups as the IROR increases. The reduction in PNW slope apparently dominates the discount rate impact for these three data groups. The opposite is true of the allowable final harvest data change which *increases* as IROR increases. In the case of final harvest data, the discount rate impact of large IROR's overcomes the decreasing PNW slope.

These equations can be solved directly for the required data accuracy under specific cost, harvest volume, price, and approximate IROR conditions. Care should be exercised in using these prediction equations because of the multicollinearity between the IROR variable, either in its inverse or simple form, and the other variables. The average simple correlation between the two sets of variables is 0.56. The correlations and signs of coefficients are all reinforcing, however, which accentuates what otherwise would be an untroublesome amount of collinearity.

Allowable data change is not associated solely with IROR as is apparent from the high significance of other variables in table 5. Also, the slope of the PNW function at the IROR is not always the same for the same IROR. The PNW functions in figure 2 all have approximately the same IROR yet their slopes vary at the IROR. IROR explains 72 percent of the PNW slope variation (footnote 1).

Because of the collinearity problem in the table 5 regressions, however, it is probably more desirable to set specific data accuracy standards based upon IROR only. This is done in table 6 where the mean allowable cost and return item data change is displayed for the 46 investment cases for each of five IROR groups. The allowable data change clearly declines as the IROR decreases for all data elements except final harvest volume data.

The allowable percentage data changes in table 6 can be used directly in setting data accuracy

TABLE 5.—*Equations predicting percentage allowable data change from a number of investment case parameters, by data element for the 1 percent upper IROR threshold*

equation \ variable	constant	IROR	1/IROR	initial cost[1]	harvest volume[2]	year final harvest	stumpage price	R^2
1. Initial cost[1]	−47.1727	+2.1771		−0.0939	+0.2129	−0.3262	+0.3392	.86
		[3](3.07)		(−3.32)	(2.14)	(−3.49)	(3.82)	
2. Commercial thinning volume	3.5384		+130.2937	+1.0584	−0.1761)	−0.1347	−0.8918	.88
			(5.40)	(6.87)	(−0.35)	(−0.28)	(−1.88)	
3. Final harvest volume[4]	−430.2490	+55.0324		+1.1413	−0.4107	+4.6278	−2.3405	.83
		(12.50)		(8.19)	(−0.79)	(8.38)	(−5.27)	
4. Stumpage price	68.4578		+45.7341	−0.1763	−1.1867	+1.3417	−0.8784	.86
			(3.15)	(−1.90)	(−3.89)	(4.71)	(−3.08)	

[1] The initial cost variable and equation refers to the cost of the initial treatment for each particular case regardless of what that treatment is. Recall that the cost change necessary to violate the upper threshold is negative. Thus, the coefficient signs must be reversed to estimate the absolute percentage cost change.

[2] The harvest volume variable equals the total of commercial thinning and final harvest volumes from the first rotation intensified management regime.

[3] The values in parentheses are calculated t-values. The two-tailed critical t-value of the 99 percent significance level is 2.70, at the 95 percent level is 2.20, and at the 9.0 percent level is 1.68.

[4] The final harvest volume equation was regressed using only 44 case observations. The two highest IROR cases, which had extremely high percentage allowable changes (16,861 and 3,353 percent, respectively) were excluded. Their inclusion would have influenced the shape of the regression considerably.

Figure 2.—The slope of the PNW function varies even for cases with similar IROR's.

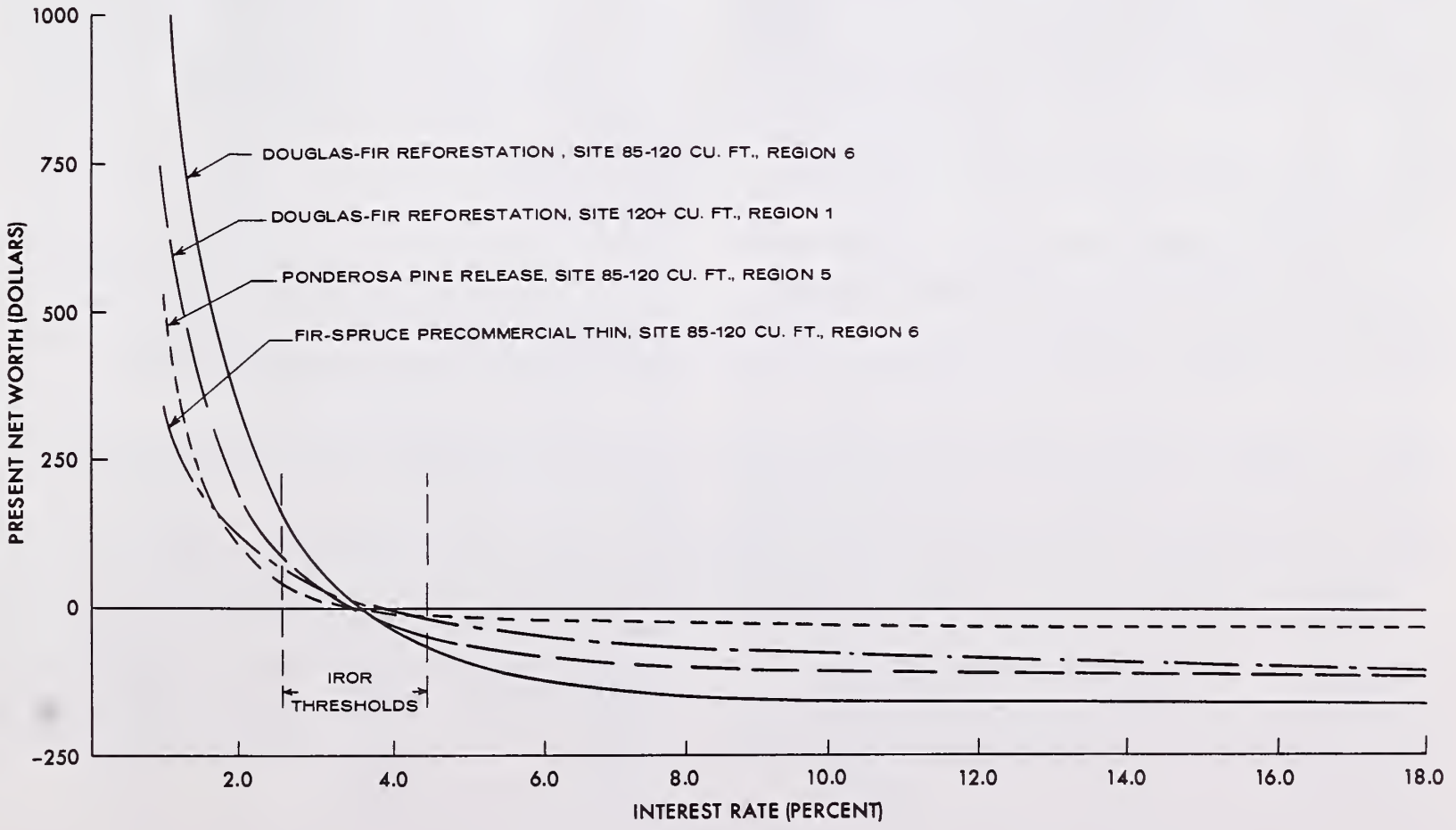

TABLE 6.—*Mean percentage change in initial cost, commercial thinning volume, final harvest volume, and stumpage price data necessary to violate the ±1 percent IROR thresholds, by IROR group*

IROR of investment	Number of cases	initial cost		commercial thinning volume		final harvest volume		stumpage price	
		+1 percent threshold	−1 percent threshold	+1 percent threshold	−1 percent threshold	+1 percent threshold	−1 percent threshold	+1 percent threshold	−1 percent threshold
(percent)		(percent)	(percent)	(percent)	(percent)	(percent)	(percent)	(percent)	(percent)
0.0–1.9	13	−75.7	576.2	212.6	−114.3	159.6	−48.9	180.6	−64.6
2.0–3.9	17	−53.7	142.8	87.1	−67.0	133.3	−48.8	92.6	−50.4
4.0–5.9	8	−37.9	72.9	55.3	−45.5	209.7	−71.8	57.2	−38.6
6.0–9.9	4	−24.5	35.5	27.0	−23.9	193.4	−91.5	32.3	−27.1
10.0–14.0	3	−21.3	28.2	22.4	−18.5	1344.2	−415.0	26.6	−22.2

requirements. For example, if an investment is suspected of having an IROR between 4 and 6 percent, the true initial treatment cost can be as much as 37.9 percent below the estimated cost and the estimated IROR will still be within 1 percent of the true IROR. Similarly, the true stumpage price may be as much as 50.4 percent below the estimated price for an investment in the 2–4 percent IROR range before the IROR is overestimated by 1 percent.

It is worth emphasizing again that these accuracy standards or allowable data changes refer to the change of one data element alone. For example, in the 4–6 percent IROR group, cost may be underestimated by 37.9 percent and IROR will still be accurate to ±1 percent, but all of the other data elements must be accurately estimated. The number of joint data changes are too numerous to evaluate and any method would require some arbitrary rule concerning the relative magnitude of the joint changes.

B. *Relative Sensitivity Between the IROR and "Computed" PNW Criteria.* Regression equations for predicting the allowable percentage data change were estimated for the "computed" PNW criteria just as they were for the IROR criteria in table 5. Elasticities of allowable data change with respect to IROR were calculated from both equations in order to compare the relative sensitivity of each criterion to IROR changes. The elasticities (table 7) are much greater for the "computed" PNW threshold than the IROR criterion.

The two criteria are also compared in table 8,

TABLE 7.—*Elasticity of allowable percentage data change with respect to IROR by two financial return criteria for major data groups*[1]

Data group	Selection criterion	
	Upper limit IROR	"Computed" PNW
initial cost	0.1675	−1.4161
commercial thinning volume	−0.5962	−4.0691
final harvest volume	0.3683	−4.3581
stumpage price	−0.2221	−3.2347

[1] The elasticity measurement uses either the IROR coefficient or the coefficient of 1/IROR, which ever occurs in the equations in tables 5 and 6. Elasticity is calculated at the mean value of allowable percentage change and the variable.

TABLE 8.—*Mean allowable percentage data change for two economic selection criteria by IROR grouping of sample cases*

IROR (percent)	Number of cases	Upper limit IROR		"Computed" PNW	
		cost data	return data	cost data	return data
0–2	13	−75.66	184.28	115.01	6496.20
2–4	17	−53.69	104.34	27.24	148.90
4–6	8	−37.89	107.38	3.76	5.43
6–10	4	−24.56	85.21	25.06	11.09
10–14	3	−21.30	464.40	40.28	11.32

where the mean percentage cost and return data change are displayed for both the ±1 percent IROR and the "computed" PNW criterion by IROR classes. Note that while on the average the "computed" PNW criterion is less sensitive to data errors than the IROR criterion, for investment cases with IROR's close to the PNW discount rate the "computed" PNW criterion is much more sensitive to data errors. Unfortunately, cases with IROR's close to the discount rate are exactly the cases which are the most difficult investment decisions because the discount rate is the alternative rate of return on investments. It is under just those conditions where the highest sensitivity with the "computed" PNW criterion occur, however.

As with all of the sensitivity relations discussed herein, this conclusion is a function of the financial return threshold concept employed. The PNW criterion is highly sensitive to data errors on cases having an IROR near the discount rate whenever the threshold is set some percentage distance from the base PNW, either through the "computed" means employed for comparison with IROR or through application of a fixed percentage PNW threshold. The same high sensitivity does not result when the PNW threshold is placed a fixed dollar limit from the base PNW. For example, when the PNW threshold is set at ±$50 from the base, the allowable percentage data changes are quite similar to the results using an absolute ±1 percent interest rate band about the IROR criterion. A fixed dollar threshold does not provide the comparability with the IROR threshold that the "computed" PNW threshold does, however.

X. CAUSES OF DATA FLUCTUATIONS AND LEVEL OF INVESTMENT CASE AGGREGATION

Previous sections have established data accuracy standards for the level of investment case aggregation employed in recent national scope analyses. If improper sampling or data compilation was the only source of data error or deviation (the first dimension of the accuracy question), the analysis could stop here. However, there is also variation of data values about the true mean because of variation of conditions within the bounds of individual investment cells. If data deviations within a cell are larger than the allowable percentage data changes and if the causes of the data variation can be identified, greater disaggregation of investment cases than employed in this analysis is warranted.

Examples of cost and stumpage price deviations are shown below along with the resource and market conditions with which these deviations are associated. These data deviations are then compared against the calculated allowable data change. Variations in yield estimates and how the yield variations compare with allowable data changes are not covered, although the same comparison could be made there, too. The allowable data changes for the 46 sample cases are aggregated by forest type group in Appendix B to facilitate the comparison with data fluctuations discussed in this section.

A. *Treatment Cost Deviations*. Four causes of treatment cost variation are covered. The first concerns the accuracy of alternative attempts at cost data gathering and tabulation. The other three deal with resource conditions which influence costs and which may warrant further analysis disaggregation. For a point of reference, the average allowable cost data change necessary to violate the upper and lower IROR thresholds in the sample cases is −51.70 percent and +189.85 percent, respectively.

1. *Alternative data sources*. Yoho et.al. (1969), McClay (1968), and Row (1973) all made estimates of the site preparation and planting cost of Southern pines. The Yoho et.al. data was collected in 1967, McClay's is for 1968 and Row's is for 1970. The mean of the cost shown in these studies is $33.33 per acre and the deviations about this mean are +44.0 percent and −40.0 percent. This variation is less than the allowable percentage change for the Southern pine sample cases, but it closely approaches the allowable change at the upper threshold (−44.68 percent) (Appendix B, table B–5 and B–6).

Palo Alto Research Associates (1970) compiled cost estimates for site preparation and planting of Douglas fir in Washington from five sources, each

adjusted to a 1970 cost level. The average cost per acre was $88.09 per acre and the maximum deviation of individual estimates from the mean is +27.9 percent and −8.4 percent. These deviations are well within the allowable percentage reforestation cost changes for the Douglas-fir sample cases, +112.34 percent and −51.72 percent (Appendix B, table B–1). In short, variability among cost estimates from alternative sources for these examples is not a significant problem.

2. *Treatment Difficulty*. Several conditions of the treated area, both of the resource and the site, influence treatment difficulty and in turn cost. Although Yoho et.al. did not measure the site factors which affect difficulty, they did compile treatment costs in the South at three levels of treatment difficulty: an "average", a "less than average", and a "more than average" difficulty. The estimated site preparation and planting cost deviated from the mean by +37.3 percent and −18.0 percent for the "more" and "less" difficult sites, respectively. This is less than half the cost deviation necessary to violate the IROR thresholds for the reforestation sample cases (Appendix B, tables B–5 and B–6).

Row (1973) also compiled site preparation and planting cost estimates by degree of site difficulty and obtained results consistent with those of Yoho et.al. Row estimated a ±27.1 percent cost deviation about the average site due to treatment difficulty which again is not enough to violate the ±1 percent IROR thresholds for the sample reforestation cases.

Yoho et.al. also estimated the cost of release treatments at the three treatment difficulty levels. In the case of release costs, the +35.1 percent and −24.8 percent deviations about the mean are great enough to violate both of the IROR thresholds for the sample cases.

Preliminary evidence indicates then that the treatment opportunity area matrix should contain a treatment difficulty dimension of at least two classes. This is necessary where release treatments are applied and probably where precommercial thinning is applied. The treatment difficulty dimension should reflect factors such as slope, rockiness, and wetness, perhaps through some combined index. Resource factors such as size and density of timber may also be important.

Similar divisions are apparently less necessary for reforestation opportunities, primarily because of the lower level of sensitivity to data errors resulting from lower IROR's. If reforestation IROR's rise, however, due to such things as higher stumpage price assumptions, the disaggregation into two treatment difficulty classes will be desirable there, too.

3. *Tract Size*. The increasing use of heavy equipment in forestry treatments greatly influences the economics of scale achieved with different tract sizes. Row (1973) prepared Southern pine cost estimates by tract size for site preparation and planting and for type conversion. Tract size impacts are measured about an 80 acre midpoint. The site preparation and planting cost per acre for 20 acre tracts is 57.3 percent higher and 640 acre tracts is 19.1 per cent lower than the midpoint. Neither of these is enough to violate the IROR thresholds of the sample cases. For the same tract sizes, however, type conversion cost varies from +90.9 percent to −26.7 percent, probably because heavier equipment is used. This is enough to violate the lower IROR threshold for the sample reforestation cases.

Two or possibly three tract size classes should be identified in the treatment opportunity area matrix for treatments which require the use of heavy equipment. Type conversion of densely stocked poletimber stands or precommercial thinning of dense stands should be differentiated by tract size classes while the classes may be unnecessary for site preparation of sparsely stocked areas.

4. *Geographic Variation*. The 46 National Forest sample cases were separated into eight regions corresponding to National Forest administrative regions. Separate cost and stumpage price estimates were made for each region. There is sometimes a question whether finer geographic divisions are desirable. Yoho et.al. estimated treatment costs for three areas in the South; the Southern Coastal Plain, the Northern Coastal Plain, and the Piedmont. The maximum cost deviations from the mean site preparation and plant cost due to the geographic divisions were only +10.8 percent and 6.8 percent, which is far below the allowable change.

The deviation of National Forest regional costs from the average national cost is not highly significant either. For example, the maximum deviation of regional site preparation and planting cost about the national average is +21.9 percent and 30.1 percent. The corresponding deviations for precommercial thinning cost are +48.4 percent and −36.1 percent. The release cost deviations are +36.0 percent and −28.0 percent. None of these

cost data deviations are enough to violate the average IROR thresholds for the sample cases, but the release and precommercial thinning deviations are close.

B. *Stumpage Price Deviations*. This section provides a sampling of causes of deviations in stumpage prices associated with a number of factors. One group of factors concerns heterogeneity of treatment aggregates caused by deviations in average stand diameter, tract size, and geographic grouping. The last factor compares the allowable data change with variations in assumed annual rates of stumpage price increase. For a point of reference, the average allowable stumpage price change on the sample cases is +100.17 percent and −45.67 percent for the upper and lower IROR thresholds, respectively.

1. *Diameter classes*. Log diameters influence the product which can be produced from a log and the product recovery ratio. The product value differential which results is reflected in stumpage price. Darr (1973) collected stumpage price data for Douglas fir sales from 1962–70 on the Bureau of Land Management's Tillamook District in Western Oregon. Sales were sorted into three average stand diameter classes: less than 20 inches, 20–30 inches, and more than 30 inches. The price relations vary considerably from year to year. The average price for 30 inch-plus stands is less then the 20–30 inch average, possibly because of differences in accessibility and cull percent. The price for the less than 20 inch sales is 17.3 percent below the mean for all the sales. The price for 20–30 inch sales is 13.9 percent above the mean. Both deviations are much less than the allowable percentage change for the Douglas fir sample cases (Appendix B, table B61).

Hazenberg (1971) estimated the stumpage price of white pine in Maine by diameter class. The average price for the 16 through 30 inch classes was $34.25 per thousand board feet. The price for the 16–18 inch classes was 47 percent below the mean and the price for the 28–30 inch classes was 40 percent above the mean.

Noreen and Hughes (1968) estimated log prices for aspen logs by diameter and product objective using a detailed conversion surplus approach. Using the product objective, which maximizes the price differential, eight-inch logs are valued 76.1 percent below the average price across all diameters. The 16-inch logs are valued 69.7 percent above the average.

From these sample studies, it seems that average stand diameter is of marginal importance as an additional disaggregation parameter. The fluctuations are close enough to the allowable data change, however, to warrant division of the area matrix and yield relations into at least two diameter classes. This is especially true for high return treatments.

2. *Tract Size*. Tract size influences harvesting cost and through that affects stumpage price. Highly capitalized logging operations experience very definite economics of scale as tract size increases. Row's (1973) stumpage price regresion equation includes a tract size variable. Using 80 acres as the mean tract size as was done with treatment costs, estimated stumpage price for 20 acre tracts is 7.7 percent lower and for 640 acre tracts is 2.2 percent higher. These deviations are very small relative to the allowable percentage stumpage price change for the sample cases and are also quite small relative to the treatment cost differences related to tract size.

3. *Geographic Areas*. Stumpage prices vary somewhat between and within National Forest regions due to such things as differences in slope, roughness of terrain, species composition, and roading adequacy. Just as with treatment cost data, there is often a question whether sufficient data variability exists to identify prices for smaller geographic areas. Geographical subdivisions may provide a helpful and inexpensive proxy approach to pick up variations in such things as slope and market conditions.

Stumpage price variations within Louisiana provide an index of geographical variation. Quarterly estimates of pine sawtimber and pulpwood stumpage prices are prepared for four separate areas within the State. For the first quarter of 1970, the maximum deviation from the State average for any one area was only +4.4 percent and −3.3 percent (Louisiana Department of Agriculture 1970), which is very low variation relative to data accuracy required for the sample cases.

Stumpage price deviations from National Forest to National Forest provide another index of geographic variation. High bid sale prices in 1970 were compiled by Region, species, and National Forest (or two parts of National Forests if an appraisal zone divided a Forest). The stumpage prices for a particular species were averaged for all of the National Forests in a particular Region. The National Forests in the Region having the upper and lower quartile stumpage prices for that

species were then compared against the Regional mean.

In Region 1, the ponderosa pine upper and lower quartile deviations are +33.6 percent and −6.7 percent, lodgepole pine deviations are +8.5 percent and −2.0 percent, and true fir deviations are +10.1 percent and −1.5 percent. These deviations are all considerably less than the allowable data changes for these species in the sample cases (Appendix B, tables B–2, B–3, and B–4). On the west side of Region 6, the quartile deviations of Douglas-fir prices are +64.8 percent and −21.9 percent, which approaches, but is also below, the allowable change for the sample cases (Appendix table A–1). In Region 8, the quartile deviations for Southern pine are +51.0 percent and −12.7 percent. The +51.0 percent is slightly greater than the average +49.8 percent allowable change for the sample cases (Appendix B, table B–5 and B–6).

The sampling of National Forest price variations indicates that most of the variation between Forests within a Region is close to the limit, but within the allowable data change in the sample cases. Because of the relatively low cost involved in recombining National Forest stumpage price information along different geographic lines, however, some alternative boundaries may be advantageous.

4. *Stumpage price inflation*. The investment cases in this analysis, as well as previously cited national analyses, assume stumpage prices will remain constant. No annual rate of real value increase was assumed. Given the long term of forestry investments, relatively small inflation rates produce large changes in assumed future prices. For example, the average year of commercial thinnings for the sample cases is 51 years and for final harvest is 86 years. The percentage increase in current stumpage prices associated with various annual rates of increase for these two periods is:

Inflation Rate	*51 Yr.*	*86 Yr.*
1 percent	66 percent	135 percent
2 percent	175 percent	449 percent
3 percent	352 percent	1171 percent
4 percent	639 percent	2817 percent
5 percent	1104 percent	6542 percent

The average annual rate of real price increase between the 1910–14 and 1968–72 average price for Douglas fir, ponderosa pine, and Southern pine from National Forests was calculated (USDA Forest Service, 1973). The rates are 4.0 percent for Douglas fir, 3.1 percent for ponderosa pine, and 3.6 percent for Southern pine. If these rates are assumed to continue, projected final harvest stumpage prices would deviate from current prices by over 1000 percent. This deviation is considerably more than the average allowable price change at the upper IROR threshold for the sample cases (100.17 percent, table 1). This is also substantially more stumpage price variation than caused by any of the previously discussed factors.

In fact, even if it is agreed that some stumpage price inflation rate should be used in the analysis, rather significant differences in assumed prices can result from alternative inflation rates. For example, Row (1973) prepared two regression equations to estimate the rate of Southern pine stumpage price increase, one in a linear form and another in a logarithmic form. Both equations were derived from observations of the same data period (1910–70), and they had comparable coefficients of determination, R^2 (.83 and .89 for the linear and logarithmic forms, respectively). In spite of all these statistical similarities, the estimated annual rate of increase was 1.8 percent from the linear form and 4.2 percent from the logarithmic form.

If these two rates are applied to the Southern pine sample cases with their average 63-year rotation, the assumed inflated price varies from $156.74 to $680.35 per thousand board feet. These estimates are ±62.6 percent from the $418.55 average of the two. The allowable percentage price deviation for Southern pine sample cases was only +49.84 percent and −35.24 percent for the ±1 percent IROR thresholds. In short, not only is the assumption of inflation rate versus no inflation rate an important one regarding the accuracy of IROR estimation, but even distinctions between different inflation rate assumptions causes significant price variation.

XI. CONCLUSIONS

The accuracy of financial return estimates in national scope timber investment studies is sometimes questioned due to feelings of data inadequacies and too great an aggregation of the investment cases. This study addresses these accuracy concerns with an analysis of the sensitivity of financial return to data errors for 46 sample investment cases. All cases are National Forest softwood

investments on sawtimber rotations representative of recent national studies. The major sensitivity conclusions are drawn using a financial return error threshold limit of ±1 percent interest rate about the base IROR of each sample case. The relative sensitivity of the IROR and PNW investment criteria was derived by placing error thresholds around the base PNW the same percentage distance that the IROR thresholds are placed from the IROR base.

Four study objectives are addressed, including:

(1) determining the general level of sensitivity of financial return estimates to data errors,

(2) identifying the investment situations where sensitivity is greatest so that data collection accuracy standards can be established,

(3) determining which resource and site parameters should be included in the treatment opportunity area matrix based upon variation caused by those parameters, and

(4) determining the relative sensitivity of IROR and PNW financial return criteria to data errors.

A. *General Level of Sensitivity*. On the average, one of the treatment cost data elements must be 52 percent too high or one of the return items must be 269 percent too low before the IROR is *underestimated* by 1 percent interest rate (table 1). Conversely, a treatment cost data element must be 190 percent too high or a return item 106 percent too low before the IROR is *overestimated* by 1 percent interest rate.

The allowable percentage data changes are large enough that any reasonable data collection procedure will, on the average, meet the required data accuracy standards. Sensitivity does vary under different investment conditions, but these results certainly defuse any accusations that the financial return results of recent national scope investment studies are useless because of data accuracy problems.

B. *Incidence of High Sensitivity and Accuracy Standards*. The IROR of the timber investment dominates the variation in sensitivity through IROR correlation with two factors. First, the slope of the PNW function at the IROR, and therefore the threshold PNW, which must be overcome by data changes, declines as the IROR decreases. Second, as the IROR increases the discount rate increases, which reduces the PNW impact of future changes. The relative balance between these two forces *tightens* the accuracy standards for initial cost, commercial thinning volume, and stumpage price data as the IROR *increases* (table 6). For final harvest volume, the accuracy standards *loosen* as IROR *increases*.

Table 6 contains the allowable percentage data change necessary to violate the ±1 percent IROR thresholds for the sample cases as the allowable change varies by IROR. Those allowable data changes can be used as data collection accuracy standards for timber investment analyses formulated similarly to the investments included here.

Notice that a high percentage of the sample cases have IROR's below four percent, which leaves few cases in the 4–14 percent range from which to derive a mean for accuracy standards. The standard deviation about the mean declines at higher IROR's, however, so there is probably no significant problem from the small sample. In particular investment situations, it is also possible to use the regression equations in table 5 or the computer program developed to derive data accuracy standards in this study (Goforth and Mills 1975).

C. *Causes of Data Variation and Analysis Aggregation*. The concern over excessive sample case aggregation was addressed by comparing resource and site associated data variations with the allowable data changes derived in the sensitivity analysis. A brief evaluation of the impact of several conditions upon stumpage price and treatment cost data variability lead to the conclusion that the treatment opportunity area matrix should be augmented with dimensions for:

(1) average stand diameter,

(2) tract size, and

(3) a treatment difficulty or operability index, particularly where heavy equipment is used.

Each of these dimensions should contain two or possibly three classes if the ±1 percent confidence level about estimated IROR is to be maintained. Modification of geographic boundaries may be employed as proxies for some of these dimensions, such as treatment difficulty, but only if direct data is not available or very expensive.

Acceptable data variation is not only a function of the impact of that variation upon estimated financial return but is also a function of data collection cost. Ideally, a marginal ratio of reduced financial return error to data collection and analysis cost should be employed to determine the

optimum data accuracy and investment case aggregation. The optimum occurs where the margins are equal for all increases in data accuracy and investment aggregation. Even when only conceptually applied, this leads to collection of some less crucial data which has low collection costs.

Variation in the assumption about the rate of future real stumpage price increases influences estimated IROR more than any of the area matrix dimensions evaluated. The impact upon IROR of several annual rates of real stumpage price increase leads to the conclusion that IROR is increased by an amount roughly equal to the assumed rate of real price increase. For example, if the IROR was 2.0 percent under a constant stumpage price assumption, the IROR will be roughly 4.5 percent if stumpage prices are assumed to increase 2.5 percent annually.

D. *Comparison of IROR and PNW Sensitivity.* The IROR vs. PNW comparison was made on the basis of a ±1 percent band about IROR and a band of equal percentage width about PNW. The IROR criterion was less sensitive to data errors for cases with an IROR near the alternative return on capital, which is just the place that lowest sensitivity is desirable. The sensitivity of the IROR criterion was also more uniform across diverse investment situations, which allows more uniform data accuracy standards.

Debate over the theoretical advantages of the IROR or PNW criterion has continued for over a decade. Webster (1965) and Haley (1969) both found that the theoretical factors had little significance in the practical problem of ranking typical forestry investments, however. Ranking of the 46 sample cases in this study by alternative investment criteria leads to the same conclusion. In light of these results, practical factors such as the management objective, ease of understanding, and sensitivity to data errors should dominate selection of an investment criterion rather than theoretical nuances.

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Appendix A.

List of Case Investments Subjected to Sensitivity Analysis

Initial Treatment	*Species*	*Region*[1]	*Site Class*[2]
Reforestation	Douglas-fir	Region 1	Site 120+
	Douglas-fir	Region 5	Site 85–120
	Douglas-fir	Region 6	Site 50–85
	Douglas-fir	Region 6	Site 85–120
	Ponderosa pine	Region 1	Site 85–120
	Ponderosa pine	Region 2	Site 50–85
	Ponderosa pine	Region 3	Site 20–50
	Ponderosa pine	Region 5	Site 120+
	Ponderosa Pine	Region 5	Site 85–120
	Ponderosa pine	Region 6	Site 50–85
	Fir–Spruce	Region 1	Site 120+
	Fir–Spruce	Region 1	Site 85–120
	Fir–Spruce	Region 2	Site 50885
	Fir–Spruce	Region 2	Site 20–50
	Lodgepole pine	Region 1	Site 85–120
	Lodgepole pine	Region 2	Site 50–85
	Longleaf–Slash	Region 8	Site 85–120
	Longleaf–Slash	Region 8	Site 50–85
	Loblolly–Short	Region 8	Site 85–120
	Loblolly–Short	Region 8	Site 50–85
Precommercial Thin	Douglas-fir	Region 3	Site 50–85
	Douglas-fir	Region 5	Site 85–120
	Douglas-fir	Region 6	Site 50–85
	Ponderosa pine	Region 3	Site 50–85
	Ponderosa pine	Region 5	Site 120+
	Ponderosa pine	Region 5	Site 85–120
	Ponderosa pine	Region 6	Site 85–120
	Ponderosa pine	Region 6	Site 50–85

	Fir–Spruce	Region 6	Site 85–120
	Lodgepole pine	Region 1	Site 120+
	Lodgepole pine	Region 1	Site 85–120
	Loblolly–Short	Region 8	Site 85–120
	Loblolly–Short	Region 8	Site 50–85
Release	Douglas-fir	Region 6	Site 120+
	Douglas-fir	Region 6	Site 85–120
	Ponderosa pine	Region 5	Site 120+
	Ponderosa pine	Region 5	Site 85–120
	Ponderosa pine	Region 5	Site 50–85
	Fir–Spruce	Region 5	Site 85–120
	Fir–Spruce	Region 6	Site 50–85
	Lodgepole pine	Region 1	Site 85–120
	Lodgepole pine	Region 1	Site 50–85
	Longleaf–Slash	Region 8	Site 85–120
	Loblolly–Short	Region 8	Site 120+
	Loblolly–Short	Region 8	Site 85–120
	Loblolly–Short	Region 8	Site 50–85

[1] Regions correspond to the Forest Service administrative regions.

[2] Site class is measured in potential cubic feet growth per acre per year at culmination of mean annual increment in fully stocked natural stands.

Appendix B

Average Levels of Sensitivity for Sample Cases by Species

TABLE B–1.—*Douglas-fir cases: The independent percentage change of separate data elements necessary to violate specified financial return estimation error thresholds, by threshold concept*

		Upper Limit IROR[1]		Lower Limit IROR[1]		Fixed percent PNW[2]		Computed PNW[3]	
	Number of Cases	Mean percent	SD	Mean percent	SD	Mean percent	SD	Mean percent	SD
Cost Data Elements									
reforestation cost[4]	4	−51.72	2.66	112.34	17.81	7.51	1.49	25.70	10.22
precommercial thinning cost[5]	3	−41.60	26.54	39.48	8.22	4.20	4.93	34.80	55.98
release cost[6]	2	−19.12	3.06	24.07	4.79	49.73	18.10	38.02	6.16
mean[7]		−41.10		72.06		15.79		31.47	
Return Data Elements									
commercial thinning volume	9	58.41	35.47	−38.61	23.80	18.63	25.30	121.95	267.57
final harvest volume	9	2409.13	5518.58	−801.78	1763.44	93.27	149.30	663.96	1561.27
stumpage price	9	68.28	62.77	−33.76	11.47	66.25	166.88	603.56	1715.29
mean		845.27		291.38		59.38		463.16	

[1] The upper and lower IROR thresholds are set 1 percent interest rate above and below the base level IROR for each case.

[2] The independent percentage change of separate data elements necessary to violate a ± 10% PNW threshold when PNW is discounted at a 5% interest rate. The threshold levels are set at $PNW_B \pm (PNW_B * 10\%)$ where PNW_B is the PNW of base input data. The sensitivity level is the same for both upper and lower thresholds. The sign of the percentage change is the same as those for IROR. PNW is calculated with a 5 percent discount rate).

[3] The "computed" PNW thresholds are set a percentage distance from the base PNW equal to (1%/IROR) for each case.

[4] The mean IROR on cases where reforestation is the initial treatment is 3.10 percent. SD stands for standard deviation of the observations about the mean.

[5] The mean IROR on cases where precommercial thinning is the initial treatment is 3.95 percent.

[6] The mean IROR on cases where release is the initial treatment is 12.86 percent.

[7] The mean IROR on all cases analyzed is 5.55 percent.

TABLE B–2.—*Ponderosa Pine cases: The independent percentage change of separate data elements necessary to violate specified financial return estimation error thresholds, by threshold concept*

	Number of Cases	Upper Limit IROR[1]		Lower Limit IROR[1]		Fixed percent PNW[2]		Computed PNW[3]	
		Mean percent	SD	Mean percent	SD	Mean percent	SD	Mean percent	SD
Cost Data Elements									
reforestation cost[4]	6	−66.19	13.88	314.42	389.46	8.66	3.02	60.42	57.20
precommercial thinning cost[5]	5	−59.24	8.04	215.01	85.10	8.50	1.21	39.64	15.48
release cost[6]	3	−51.79	8.45	160.84	72.86	6.15	2.54	19.30	11.96
mean[7]		60.62		240.74		8.07		44.19	
Return Data Elements									
commercial thinning volume	14	117.48	121.54	−77.18	53.65	92.91	174.05	923.22	2182.87
final harvest volume	14	130.07	88.51	−47.09	26.44	198.54	355.41	1794.14	3749.58
stumpage price	14	128.33	46.17	−58.43	11.03	102.11	118.85	812.09	1367.03
mean		125.29		60.90		131.20		1176.48	

[1] See footnote 1 in table B–1.
[2] See footnote 2 in table B–1.
[3] See footnote 3 in table B–1.
[4] The mean IROR on cases where reforestation is the initial treatment is 2.46 percent. SD stands for standard deviation of the observations about the mean.
[5] The mean IROR on cases where precommercial thinning is the initial treatment is 2.34 percent.
[6] The mean IROR on cases where release is the initial treatment is 3.51 percent.
[7] The mean IROR on all cases analyzed is 2.65 percent.

TABLE B–3.—*Fir Spruce cases: The independent percentage change of separate data elements necessary to violate specified financial return estimation error thresholds, by threshold concept*

	Number of Cases	Upper Limit IROR[1]		Lower Limit IROR[1]		Fixed percent PNW[2]		Computed PNW[3]	
		Mean percent	SD	Mean percent	SD	Mean percent	SD	Mean percent	SD
Cost Data Elements									
reforestation cost[4]	4	−76.47	25.17	125.89	33.70	10.15	2.11	129.19	126.69
precommercial thinning cost[5]	1	———	———	———	———	———	———	———	———
release cost[6]	2	−43.74	21.89	144.43	143.37	4.95	5.28	19.95	24.98
mean[7]		56.19		108.13		7.21		79.52	
Return Data Elements									
commercial thinning volume	7	176.71	180.21	−60.97	44.27	236.34	396.17	4722.02	9542.15
final harvest volume	7	201.49	120.03	−56.71	28.62	553.20	1099.46	12070.70	27726.18
stumpage price	7	110.12	76.16	−41.87	11.80	179.36	303.01	3594.54	7602.18
mean		162.77		53.18		322.97		6795.75	

[1] See footnote 1 in table B–1.
[2] See footnote 2 in table B–1.
[3] See footnote 3 in table B–1.
[4] The mean IROR on cases where reforestation is the initial treatment is 1.69 percent. SD stands for standard deviation of the observations about the mean.
[5] The mean IROR on cases where precommercial thinning is the initial treatment is 3.81 percent.
[6] The mean IROR on cases where release is the initial treatment is 3.82 percent.
[7] The mean IROR on all cases analyzed is 2.62 percent.

TABLE B–4.—*Lodgepole Pine cases: The independent percentage change of separate data elements necessary to violate specified financial return estimation error thresholds, by threshold concept.*

	Number of Cases	Upper Limit IROR[1] Mean percent	Upper Limit IROR[1] SD	Lower Limit IROR[1] Mean percent	Lower Limit IROR[1] SD	Fixed percent PNW[2] Mean percent	Fixed percent PNW[2] SD	Computer PNW[3] Mean percent	Computer PNW[3] SD
Cost Data Elements									
reforestation cost[4]	2	−77.38	18.72	——	——	11.00	.78	147.70	110.73
precommercial thinning cost[5]	2	−61.17	3.11	191.38	26.39	9.37	.27	70.38	18.85
release cost[6]	2	−71.41	6.20	1193.02	999.62	9.60	.25	71.32	15.63
mean[7]		69.99		553.76		9.99		96.47	
Return Data Elements									
commercial thinning volume	6	161.64	146.11	−108.18	34.61	167.16	269.06	2661.32	5474.66
final harvest volume	6	111.51	72.78	−42.56	15.11	290.92	345.00	4095.90	7115.55
stumpage price	6	159.20	39.75	−59.14	3.41	232.26	146.50	2639.90	2967.23
mean		144.12		69.96		230.11		3132.37	

[1] See footnote 1 in table B–1.
[2] See footnote 2 in table B–1.
[3] See footnote 3 in table B–1.
[4] The mean IROR on cases where reforestation is the initial treatment is 1.01 percent. SD stands for standard deviation of the observation about the mean.
[5] The mean IROR on cases where precommercial thinning is the initial treatment is 1.88 percent.
[6] The mean IROR on cases where release is the initial treatment is 1.38 percent.
[7] The mean IROR on all cases analyzed is 1.25 percent.

TABLE B–5.—*Longleaf and Slash Pine cases: The independent percentage change of separate data elements necessary to violate specified financial return estimation error thresholds, by threshold concept*

	Number of Cases	Upper Limit IROR[1] Mean percent	Upper Limit IROR[1] SD	Lower Limit IROR[1] Mean percent	Lower Limit IROR[1] SD	Fixed percent PNW[2] Mean percent	Fixed percent PNW[2] SD	Computed PNW[3] Mean percent	Computed PNW[3] SD
Cost Data Elements									
reforestation cost[4]	2	−43.39	1.42	89.36	3.30	1.25	1.26	2.69	2.77
precommercial thinning cost	0	——	——	——	——	——	——	——	——
release cost[5]	1	——	——	——	——	——	——	——	——
mean[6]		28.93		59.57		.83		1.79	
Return Data Elements									
commercial thinning volume	3	68.75	45.62	−56.56	35.89	3.93	3.38	6.04	4.57
final harvest volume	3	169.39	44.53	−81.08	16.01	6.32	7.03	8.76	7.26
stumpage price	3	56.83	22.88	−38.69	10.97	3.52	3.77	4.96	4.02
mean		98.32		58.78		4.59		6.59	

[1] See footnote 1 in table B–1.
[2] See footnote 2 in table B–1.
[3] See footnote 3 in table B–1.
[4] The mean IROR on cases where reforestation is the initial trèatment is 4.77 percent. SD stands for standard deviation of the observations about the mean.
[5] The mean IROR on cases where release is the initial treatment is 8.82 percent.
[6] The mean IROR on all cases analyzed is 6.12 percent.

TABLE B–6.—*Loblolly and Shortleaf Pine cases: The independent percentage change of separate data elements necessary to violate specified financial return estimation error thresholds, by threshold concept*

	Number of Cases	Upper Limit IROR[1]		Lower Limit IROR[1]		Fixed PNW[2]		Computed PNW[3]	
		Mean percent	SD	Mean percent	SD	Mean percent	SD	Mean percent	SD
Cost Data Elements									
reforestation cost[4]	2	−45.97	3.62	104.74	20.13	2.89	2.98	7.11	7.79
precommercial thinning cost[5]	2	−23.07	2.47	32.10	4.74	37.03	18.32	37.01	12.86
release cost[6]	3	−23.97	2.96	34.37	6.12	26.72	16.14	28.66	12.93
mean[7]		30.00		53.83		22.93		24.89	
Return Data Elements									
commercial thinning volume	7	42.59	29.87	−36.55	24.74	7.37	3.17	10.23	7.26
final harvest volume	7	228.01	79.72	−105.66	35.36	13.66	5.97	18.77	12.88
stumpage price	7	42.85	22.12	−31.79	11.22	6.75	2.87	9.20	5.97
mean		104.48		58.00		9.26		12.73	

[1] See footnote 1 in table B–1.

[2] See footnote 2 in table B–1.

[3] See footnote 3 in table B–1.

[4] The mean IROR on cases where reforestation is the initial treatment is 4.41 percent. SD stands for standard deviation of the observations about the mean.

[5] The mean IROR on cases where precommercial thinning is the initial treatment is 9.73 percent.

[6] The mean IROR on cases where release is the initial treatment is 8.80 percent.

[7] The mean IROR on all cases analyzed is 7.81 percent.

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Mills, Thomas J., Marcus H. Goforth, and Thomas P. Hart.
1975. Sensitivity of estimated financial returns on timber investments to data errors. USDA For. Serv. Res. Pap. WO–31, 23 p.

Concern is frequently expressed that financial return estimates in national scope timber investment analyses are unreliable because of excessive data errors.

This study addresses the concern through a sensitivity analysis by: determining the general level of sensitivity to data errors, determining sensitivity in order to set data collection accuracy standards, comparing stumpage price and treatment cost variations with allowable data changes to determine the proper level of investment case disaggregation, and comparing the relative sensitivity of the internal rate of return and present net worth investment criteria.

Results indicate that general sensitivity to data errors is relatively low, and that financial return estimates are more sensitive to data errors for cases with high rates of return. Average stand diameter, tract size, and treatment difficulty all influence stumpage prices and/or treatment costs enough to make them separate dimensions in the area matrix used to define potential treatment opportunities. Also, the internal rate of return criteria proved less sensitive to data errors at crucial decision points than the present net worth criteria.

KEYWORDS: Sensitivity analysis, investment criteria, data accuracy standards

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